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Propulsor Hydrodynamics

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Theme lecture

It is a great honour and privilege to be invited for this theme lecture on Propulsor Hydrodynamics.

The session will cover a wide variety of propulsors and their many different aspects in detail and ***the purpose of this talk, as I understand it, is to provide some guide lines and perspectives, which will protect us from getting lost under way.***

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Perspective: *future*

The perspectives are clearly my personal views of the future developments based on forty years of work at VWS, the Berlin Model Basin, documented in great breadth and depth on my website.

But ***this does not imply that I will be telling anecdotes. I shall rather talk about the future: the origin, development and future of ideas, of basic models, underlying 'assumptions'***, usually not explicitly stated in reports and papers, but *of crucial importance for the success and value of the work reported.*

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Personal background

Since 1903 until the end of the war VWS has been the German navy tank, being completely destroyed during the war, and later rebuilt as an institute, reporting to the city of Berlin, doing navy work only secretly, as secret as possible under Russian eyes.

Only after the unification of Germany VWS has become part of the Technical University Berlin and has been closed down at the end of 2001.

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First tasks, *1961 …*

My first tasks at VWS have been systematic tests with a ducted propeller, 1961, as well as theoretical investigations of unconventional propulsors. ***These tasks forced me to reconstruct the basic theory of propulsion from first principles.***

My results on hull-duct interaction contradicted the deeply rooted beliefs of my director and my supervisor so much that the report was not filed as a VWS Report proper and was banished into the basement.

But ideas and data cannot be locked up.

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… sheds light

Based on this experience my rational theory of propulsion has been conceived some years later, since 1968, explicitly since 1980, and developed over the last twenty five years until now.

As neither conventional propeller designs nor powering predictions belonged to my duties at the model basin ***the whole development took place beside the main-stream, thus permitting to shed light on that stream and its future developments*** *(Feyerabend)*.

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My motto

Paul Feyerabend (1965):
'Immediate plausibility and the agreement with the usual jargon indicate - far from being philosophical virtues **- that not much progress has been achieved or will be achieved.'**

*Do not try to grasp all details of the picture I try to draw in my presentation, but **follow the main lines of my thoughts** **and only afterwards try to find out the impact on your own work**!*

Outline of paper

Some philosophy: *identification*
traditional configurations
traditional trials: *speed/power*
quasisteady trials: *interactions*
explicit theory: *new axioms*
a 'model' test: *of two minutes*
full scale tests: METEOR, CORSAIR
advanced configurations
mechanism: *propulsors as pumps*
design: *thrust as nasty by-product*
some conclusions: *what next?*

Basic models

If we do not understand the **purpose and working principle** of propulsors and do not know how to **evaluate their performance**, how can we talk in a meaningful way about their hydrodynamics?

In the rational theory of propulsion p***ropulsors are conceived as pumps*** and the ***concept of equivalent propulsors,*** one of the great achievements in ship theory, due to *Fresenius (1924)*, is considered as key powertool, exploited in Berlin by Horn and later Schmiechen.

Contra inductive

Experience and tradition are **not very interesting *per se, especially if somebody or even whole generations do the 'wrong' things for decades*.**
So do not belief anybody, *not even me*, but stick to the slogan of rationalism:
***sapere aude*, dare to think yourself**.

*When I wanted **to reconstruct ship theory for my purposes at hand I did not ask naval architects, but rather 'architects' of theories.***

'Metaphysics'

Propulsor hydrodynamics is embedded into ship theory and, even more basic, hydromechanical systems theory, a subset of classical mechanics.
The concepts of ship theory have to be distinguished cleanly from their interpretations in terms of results of hydrodynamical experiments, physical and/or numerical.

Our basic requirement is that our 'laws' should be 'objective', independent of our units of measurement.

Buckingham's theorem …

Theorem. *The assertion that the relation*

$$Q_0 = f\,(Q_1, Q_2, \dots\, Q_{n-r} \dots\, Q_n)$$

is unit-free is equivalent to a condition of the form

$$\Pi_0 = \phi\,(\Pi_1, \Pi_2, \dots\, \Pi_{n-r})$$

for suitable dimensionless power-products Π of the Q, where
n denotes the number of influence magnitudes Q, homogeneous in the basic units, and
r denotes the number of independent basic units: in mechanics r = 3.

… says nothing …

The theorem says nothing about the number and type of parameters to be chosen and the format of the unit-free function. This information is ***a matter of experience**, past or present, **not necessarily of hydrodynamics***.

The parameters can be changed to others, amounting to a change to oblique coordinates in logarithmic scales.

Although everybody learns this at school hardly anybody draws the conclusions.

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Aggregate dscriptions

The reduction in the number of parameters by three appears to be large, but the number of mostly geometrical parameters necessary to describe a hydromechanical system is usually very large.

As a consequence aggregate or global parameters, typically 'characteristic' lengths are of interest, usually a matter of more, mostly less educated guess work.

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Example: Speed trials

Often the problem can be solved pragmatically. Let us consider as a simple, but most fundamental example the powering performance of a ship at given loading condition and speed.

In this case the power ratio

$K_P \equiv P / (\rho\, D^5\, N^3)$

is assumed to be a function

$K_P = f_P\,(J_H)$

of the hull advance ratio

$J_H \equiv V / (D\, N)$.

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Practical limitations

Due to the very small variability of the data *the most general function that can be identified with confidence* is a linear function

$K_P = K_{P\,0} + K_{P\,H}\, J_H$.

With the ship speed over ground, to be measured by GPS, and the unknown current speed over ground the hull advance ratio is

$J_H = J_G - J_C$.

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More pragmatism

Again the problem can be solved pragmatically by introducing formally a polynominal law for the unknown current velocity as function of time

$V_C = \Sigma_i\, v_i\, t^i$.

This completes the model as far as it is of interest here.

The few parameters of the model can be identified from the usually very few data collected at speed trials.

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ISO 15016: 2002-06

And Buckingham's theorem says nothing about the values of the parameters. *This is a matter of experiments.*

The following two slides show results of evaluations of the data provided with the example of the recently agreed standard ISO 15016: 2002-06.

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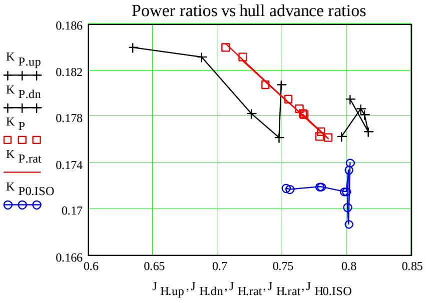
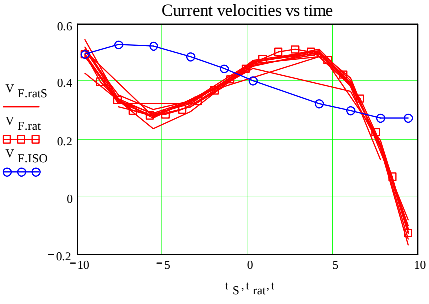
Propeller 'behind': ISO example



Current: ISO example



Grandfathers' practice

The important observation is that, *contrary to the poor results of the recently standardized practice of our grandfathers* based on hydrodynamic *considerations*, **the rational evaluation of speed trials provides perfect results *without any reference to hydrodynamics whatsoever***.

I only mention that the same methodology can be used to determine the performance at no wind and no waves.

'Opposition'

The international agreement has been reached although the foregoing results have been communicated in time to all organisations and bodies involved.

Only the Korean colleagues have opposed the new standard, but for the wrong reason. They wanted to introduce more hydrodynamics, more a fancy sea-keeping theory 'based' on shaky grounds, crude estimates of the sea state.

'Regula falsi'

The failure of the traditional method confirms a basic rule in hydromechanical experiments: *If the flow velocity has not been estimated correctly you can safely forget everything else.*

In the meantime colleagues have confirmed that *the method suggested by ISO* 15016 is *error prone and lacking transparency*.

Naval architects have to ask themselves: *How long will ship owners, e. g. Navies, accept this state of affairs?*

Deeply rooted beliefs

This very simple, but fundamental example clearly shows that *the present, very involved practice is based on superfluous assumptions*, to put it mildly.

But who likes to be told that his *deeply rooted beliefs are plain superstition*? So far I have not met anybody, including myself! *Finally some colleagues started to use the procedure I have proposed.*

The last trials data I had a chance to evaluate are those of a ship with *adjustable pitch propeller*.

Inspectional analysis

Not all problems are as simple as the evaluation of speed trials. ***A rational procedure to arrive professionally, without guess work at formats and parameters of unit-free functions is***

- to adopt axiomatically some simple, though adequate hydromechanical model and
- to perform a dimensional analysis, *an inspectional analysis* (*Birkhoff*).

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Emotional reactions

The important observation is that the theory is essentially a normative theory, models unfolding representation spaces, the parameters being the 'coordinates' of the systems considered.

When I tell hydrodynamicists that their only task is to identify the values of the parameters defined by ship theory, *their reaction is usually quite emotional.* ***Their reaction does not change the situation, but supports my argument.***

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Systems identification

Identification is essentially a matter of experiments, either physical or computational, and their evaluation as in the foregoing example.

The important point is that these sub-tasks can be performed *professionally*, preferably *not* by hydrodynamicists.

To put it bluntly: ***There are too many hydro-dynamicists in towing tanks!***
Even the the calibration of balances requires experts in systems identification.

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ITTC Quality manual

In view of this fact the ITTC had a hard time finally to come back to its original task, to agree on standard procedures, and accordingly the Quality Systems Group has established a quality manual according to ISO 900x under its chairman Strasser, SVA Vienna.

In future much more work needs to be done along the conceptual lines I am outlining today.

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ITTC Committees

During the period of the 23rd ITTC apart of the Propulsion Committee three Specialist Committees have been dealing with matters of propulsion:

Speed and Powering Trials,
Procedures for Resistance, Propulsion and Open Water Tests,
Validation of Waterjet Test Procedures.

I cannot possibly attempt to scrutinize all their findings, but just one.

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Speed and Powering Trials

The report of the Specialist Committee provides a comparison of all trials codes currently in use. The method proposed has been considered as '*a category by itself. It does not really follow the same format as all the other methods and hence was not used in the comparison of factors reviewed in each method*.' Purposely it does not!

According to my experience and the ISO example the problem is not so much to analyze random errors, but ***the dominant problem is still to avoid conceptual and systematic errors.***

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Big surprise

To my big surprise the Specialist Committee on Speed and Powering Trials has been discontinued. Evidently the governning bodies 'felt' that all problems have been solved.

On the other hand a Specialist Committee on Powering Performance Prediction has been established, charged with the task which traditionally has been the essential task of the Propulsion Committee and *to which I will turn now.*

Hull-propeller interactions

Again I shall provide an example of fundamental importance to our profession, *further analysis of the powering performance, of hull-propeller interactions in particular*, *<u>required for the powering performance predictions</u>*.

Without going into the details I shall scan through the theory in order to provide some background for the discussion of the results in particular and in general.

Axiomatic models

Required is a more detailed model and the acquisition of additional, thrust data, necessary for the identification of the additional parameters introduced.

The most convenient way to provide an adequate model is ***the axiomatic use the hydrodynamic theory of ideal propulsors in ideal displacement and energy wakes***. *Up to now this has been done implicitly, rather vaguely, my suggestion is to do it explicitly.*

Rational conventions

This model provides for conventions, which are implicit or coherent definitions of the hull resistance of a ship with propeller and the propeller advance speed in the behind condition.

Again hydrodynamicists are up-set by this crude, 'mechanical engineering' use of their sacred science.

Froude's tests replaced

But this is the only rational way to solve the basic problems at hand: to replace hull towing tests and propeller open water tests.

In case of advanced hull propeller configurations the latter tests <u>provide useless data</u> and, most importantly, they <u>cannot be performed on full scale under service conditions</u>.

Momentum balance

The first basic equation is the momentum balance

$$m\,a + R(V) = T\,(1 - t)\,.$$

In view of the limited variability of the data often the *local* resistance law

$$R(V) = r_0 + r_1 V + r_2 V^2/2$$

with the three parameters r_i may be adopted.

If the tests cover a wider range there is no problem to generalise this 'law' appropriately.

Thrust deduction function

The complete thrust deduction function is

$$t = (1 + \tau + \chi) / \tau - [(1 + \tau + \chi)^2 - 2\,\tau\,\chi]^{1/2} / \tau$$

with the relative velocity increase as function of the jet efficiency

$$\tau = 2\,(1/\eta_{TJ} - 1)$$

and a parameter not occuring in the traditional analysis, the displacement influence ratio

$$\chi \equiv w_D / (1 - w_E - w_D)\ ,$$

different at model and ship due to scale effects.

Thrust deduction axiom

Of interest is the global approximation

$$t \approx 0.56\,\chi\,\eta_{TJ}$$

leading to the plausible thrust deduction axiom

$$t = t_{TJ}\ \eta_{TJ}$$

with the parameter

$$t_{TJ} = \text{const}\ .$$

The four parameters introduced are obtained as solution of a system of linear equations *provided the jet efficiency has been determined before*. And this problem can be solved as follows.

Energy balance

The second basic equation is the energy balance for the propeller

$$T\,V\,(1 - w) = \eta_{TJ}\,\eta_{JP}\,P_P$$

with the the 'ideal' or jet efficiency

$$\eta\,T_J \equiv P_T / P_J$$

and the 'hydraulic' or pump efficiency

$$\eta_{JP} \equiv P_J / P_P\ .$$

Usually naval architects do not separate these efficiencies, although only its pump efficiency permits to judge the quality of a propulsor.

Wake function

The theoretical function for the jet efficiency is

$$\eta\,(1 - w) / \eta_{JP} = 2 / [1 + (1 + c / (1 - w)^2)^{1/2}]$$

with the apparent propeller load ratio

$$c \equiv 2\,T / (\rho\,V^2\,A)$$

and the apparent propeller efficiency

$$\eta \equiv T\,V / P_P\ ,$$

both obtained from measured magnitudes.
Solving for the wake ratio results in the function

$$w_1(\eta_{JP}) = c\,\eta / (4\,\eta_{JP}) - \eta_{JP} / \eta + 1\ .$$

Wake axioms

The 'plausible' wake axioms are

$$w = w_{TJ}\,\eta_{TJ}$$

with the parameter

$$w_{TJ} = \text{const}\ ,$$

and the further axiom concerning the pump efficiency in the range of interest

$$\eta_{JP} = \text{const}\ .$$

Thus the second explicit condition is

$$w_2(\eta_{JP}, w_{TJ}) = 1 / [1 + \eta_{JP} / (\eta\,w_{TJ})]\ .$$

Wake: iterative solution

The equation

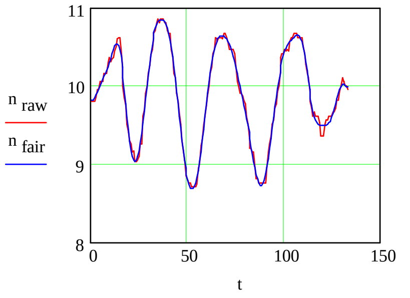
$$w_1(\eta_{JP}) = w_2(\eta_{JP}, w_{TJ})$$

for the parameters is non-linear und has to be solved iteratively.

After the solution has been reached all powering performance parameters may be determined in the range of observed hull advance ratios.

The following slides contain results of a model test compared with results of the traditional evaluation based on resistance and propeller tests.

Raw data: rate of revolutions



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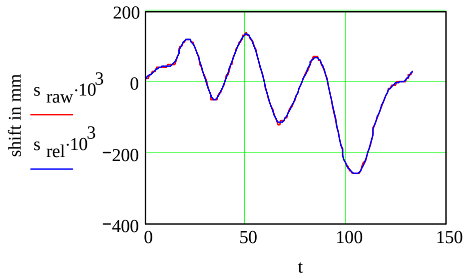
Raw data: relative surge



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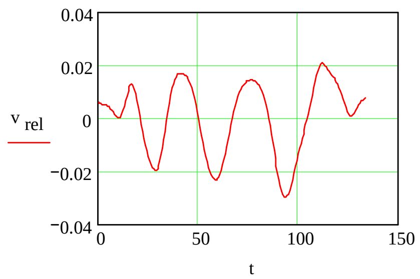
'Derived': relative speed



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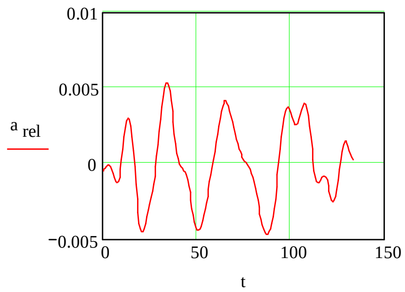
'Derived': acceleration



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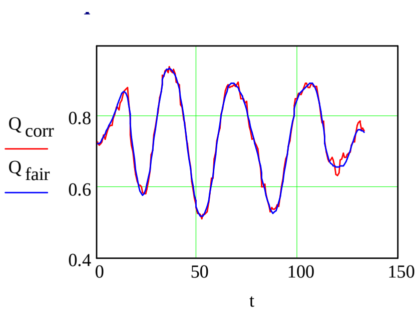
Raw data: torque



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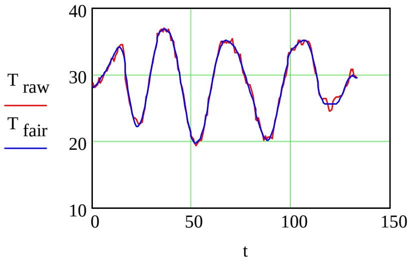
Raw data: thrust



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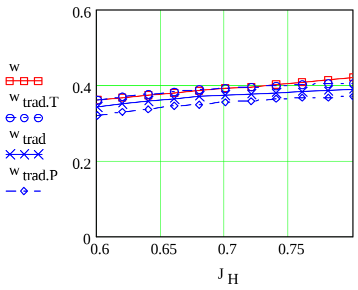
Wake fractions



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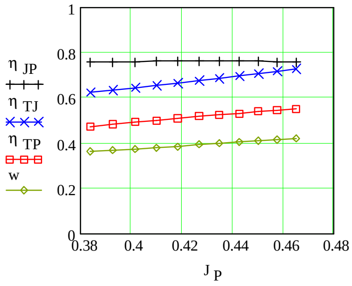
Equivalent open water



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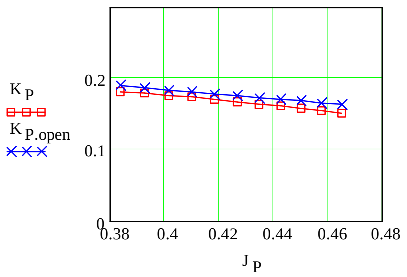
Power ratios $K_P = 2\pi K_Q$



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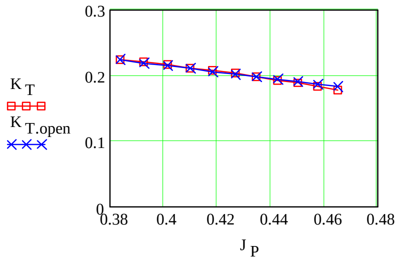
Thrust ratios



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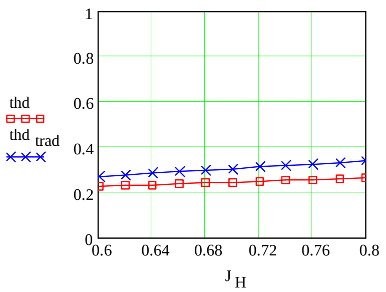
Thrust deduction fractions



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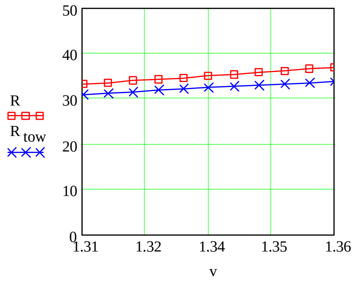
Resistance values



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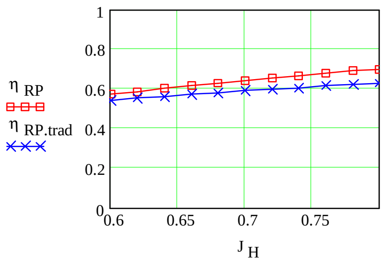
Propulsion efficiencies



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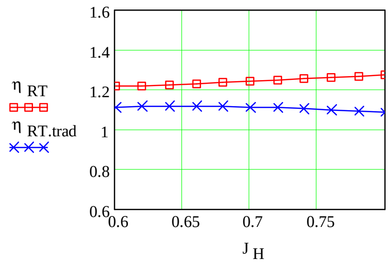
Hull 'efficiencies'



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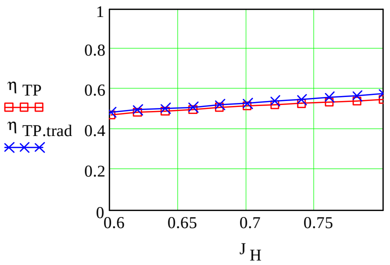
Propeller efficiencies 'behind'



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Coherence over all

Thus the coherent model and the coherent set of data obtained from a quasisteady model test of only two minutes duration permit to identify coherent results in a wide range of propeller advance ratios.

This technique is the only meaningful in case of wake adapted propellers, pre- and post-swirl configurations, partially submerged propellers etc.

The paper of Kooiker et al is concerned with the importance of coherent measurements in the context of cavitation and pressure fluctuations.

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'Real' advantages

At low propeller loading the losses at additional surfaces of pre- and post-swirl systems out-balance the gains. *Thus only 'contra'-sterns and -rudders requiring no extra surfaces offer 'real' advantages.*

Before the war already thirty percent of the tonnage was fitted with 'twisted' sterns and rudders. Since the war each generation of naval architects has re-invented the idea, but I have not heard of routine applications, the new Becker rudder may become.

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Some history and …

Horn's early attempts to solve the problem of wake in 1935/37 suffered from conceptual limitations and deficiencies of the measuring and computing techniques in those days.

They were finally disrupted by the war and started anew with my axiomatic theory in 1980. From there on it took me twenty-five years of hard work to reach the present state of maturity.

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… future possibilities

Anybody, not totally blind on both eyes, will see the technological and commercial advantages of the procedure, not even requiring a towing carriage.

E. g. extended experimental studies necessary for the validation of computer codes can thus be performed *very quickly, very cheaply and, last but not least, most reliably over wide ranges of parameters*. Necessary changes of the geometrical parameters pose 'the only real' problem in this context.

Incoherence

The Propulsion Report at the 23rd ITTC deals with the well known scale effects in model screw propeller performance essentially without drawing consequences. The usual 'way out' is to perform open water tests, even with wake adapted propellers, at 'sufficiently' high Reynolds numbers.

But in model propulsion tests the propellers are usually run at much lower Reynolds numbers, though in the behind condition. ***<u>And the powering performance analysis is based on these two sets of incoherent data!</u>***

Partial similarity

Consequently my opinion is that model test should not be performed at slow speeds.

At slow speeds we are picking up more scale effects, unnecessarily aggravating the problem of partial similarity. Accordingly I have evaluated METOR model data only at the model service speed.

Finally …

At the 23rd ITTC Holtrop reported on quasi-steady testing at MARIN. In the 'hybrid' model adopted the inertial term is missing. So the question arises: Is the inertia being treated statistically, assumed to vanish in the average?

Some forty years ago in a Japanese study it has been shown, that due to the large masses involved even very small accelerations, less than a thousand of a 'g', may easily upset the momentum balances.

… ill-defined averages

And I have observed that taking averages or, even worse, relying on ill-defined averages provided by somebody else may be 'exactly' the wrong thing to do.

Traditional methods usually rely on <u>steady conditions, not averages</u>, and thus the steady conditions may have <u>to be carefully 'established' or constructed</u>!

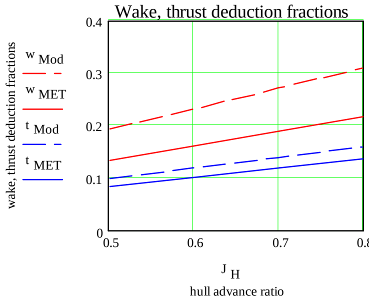
Full scale tests

As has been mentioned the method can be applied on full scale. Results of full scale tests with the German research vessel METEOR in November 1988 in the Arctic Sea have been compared with results of corresponding model tests providing scale effects in wake and thrust deduction fractions, ***for the first time worldwide***.

These scale effects are the corner stones of reliable powering performance predictions.

METEOR: Test conditions, *1988*

METEOR: Scale effects



Partially submerged propellers

Quasi-steady tests have also been performed on model and full scale with the experimental air-cushion vehicle CORSAIR/MEKAT of B+V fitted with partially submerged propellers.

As described in the paper by Shibu the latter for various reasons are of great interest to Navies. 'Accordingly' there is little published information available.

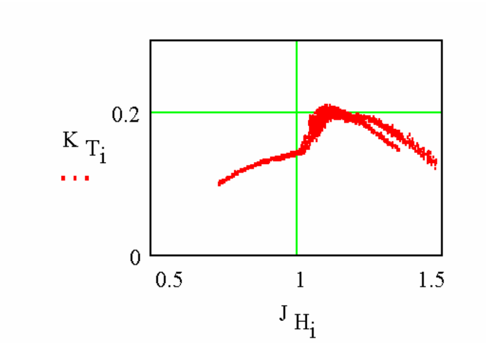
Systematic series

The present and future work and publications of Suresh and Suryanarayana promise to change that situation, although their systematic series is limited to the open water performance.

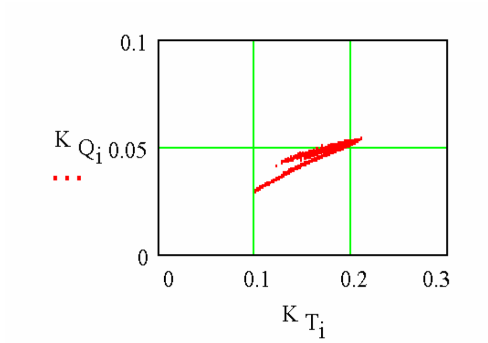
To my knowledge the question of adequate modelling has not been answered yet.

The following slides show results of propellers behind the CORSAIR model tested in the large circulation tunnel UT2 of VWS.

Model $K_T = f(J_H)$

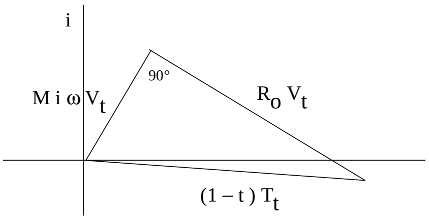


Model $K_Q = f(K_T)$



Complex force diagram

First harmonics of covariance functions, constant thrust deduction fraction assumed



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Values identified

The following values have been identified from quasi-steady propulsion right before the 'hump'

N_m	10.84	Hz
V_m	5.878	m/s
A_m	-0.001	m/s^2
T_m	73.70	kN
M	158.9	t
R_V	39.54	kN s/m
t_m	0.020	1
R_m	72.47	kN

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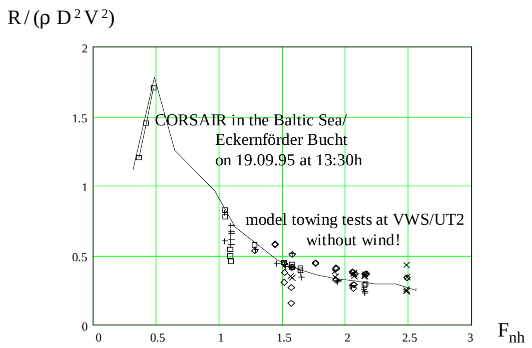
Resistance: shallow water



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Super-cavitation

The paper by Rath et al is discussing the design of super-cavitating propellers. But from the abstract it is not quite clear whether the authors are really designing super-cavitating or partially submerged propellers.

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Innovative solutions

Going back to first principles fundamental problems of ship theory so far unsolved have been solved. Although everybody is talking about the need for full scale tests, the ITTC has discontinued the Specialist Committee on Trials and Monitoring!

The institute that first will introduce the techniques described will certainly be at the forefront of the scientific and professional development. Not only Navies can use the technique for monitoring and research purposes.

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Podded propellers

The paper of Go et al is concerned with the problem of model testing and power prediction for large ships with a CRP-POD system. In case of podded drives Froude's test technique using hull towing and propeller open water tests appears to be adequate.

But *if the method of model testing described before is developed for application not only on model scale, but on full scale as well, the scale effects of interest can be determined directly.*

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Essential point

The essential point of the rational procedures is to get away from the ever more detailed models generating more problems than solving them and to move towards highly aggregate models with only few parameters to be identified from the usually few data available.

This permits to evaluate trials without reference to model test results and other prior information, as it should be. ***Unless we start evaluating trials as objectively as possible we cannot reasonably talk about optimum solutions and scaling.***

Advanced configurations

The solutions sofar have been based on the naive conception of a propulsor as thruster over-coming the resistance of the hull to be propelled.

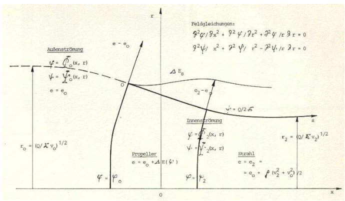
In advanced hull-propulsor configurations, maybe pump jets, 'starting' with ducted propellers, **this point of view is no longer adequate**, ***thrust is no longer a meaningful measure of performance and goal of design.*** *Consequently the concept is to be‘deleted from our intellectual inventory’.*

Propulsors as pumps

An alternative much more adequate and efficient conception is to consider propulsors as pumps *feeding energy into the fluid and establishing the condition of self-propulsion*, vanishing net momentum flow into the hull-propulsor system.

The simplest of such pumps are ducted propellers. The ideal ducted propeller provides a much more 'realistic' model of a propulsor than the actuator disc, suffering from edge singularity.

Ideal ducted propeller, *1978*



- outside flow: flow around a sink
  sink ‘strength’ < propeller flow rate!!!
- actuator: finite potential force field
- boundary stream line (duct): force free!

Purpose of ducts

The sketch clearly shows that the purpose of ducts is
- *not* to provide thrust
- *but* to avoid edge singularities
  and thus approach ideal propeller performance.

Most expositions of the theory of duct are quite inadequate and misleading, based not on hydro-dynamics but professional superstition.

The higher the thrust of the duct the higher the frictional losses at the duct and the danger of cavitation at the actuator.

Outdated designs

Most design methods are still concerned with ducted propellers in open water. And the methods to deal with hull-propeller interactions are too crude*, to say it politely.*

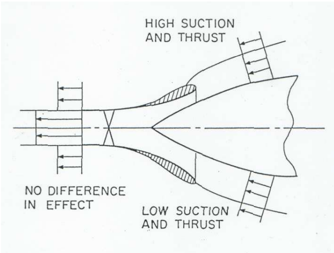
In view of the fact that interactions mostly take place between hull and duct this approach is neither realistic nor acceptable. At the extreme condition in the following sketch

$T_A = T_{AE}$,

$T_D = T_{DE} + t\,T$.

Daniel Bernoulli in action

Suction at the hull and thrust at the duct <u>constitute an energetically neutral hydrodynamical short circuit.</u>
Busmann, STG 1935,
Schmiechen, ONR 1968.



Basic magnitudes

Pre-requisite for an efficient description and treatment of the problems at hand are adequate languages, concepts and propositions.

Speed of ship V_H, power supplied P_P,
density of fluid ρ, volume flow rate Q,
energy flow at entry $E^F{}_E$ / at exit $E^F{}_J$.

For equivalent propulsors, *being formal constructs*, *not real propulsors*, outside the displacement wakes 'far behind, in the energy wake alone' the magnitudes are the same.

Derived: energy velocities etc

Energy velocities	$V_X \equiv (2\, E^F{}_X / (\rho\, Q))^{1/2}$
energy wakes	$w_X \equiv 1 - V_X / V_H$
energy densities	$e_X \equiv E^F{}_X / Q$
actuator head	$\Delta e \equiv e_J - e_E \equiv \Delta E^F{}_X \equiv$
	$\equiv \rho\, (V_J{}^2 - V_E{}^2)/2$
'momentum' flows	$M_X \equiv \rho\, Q\, V_X \equiv$
	$\equiv (2\, \rho\, Q\, E^F{}_X)^{1/2}$

Axioms

The energy balance with the jet power

$$P_J = E^F{}_J - E^F{}_E = Q\, \Delta e\ .$$

The momentum balance

$$m\, d_t\, V_H + R_E = T_E + F\ ,$$

at steady condition of self-propulsion

$$R_E = T_E$$

with the effective thrust

$$T_E = M_J - M_E = \rho\, Q\, (V_J - V_E)\ .$$

Performance criteria

Independent of the design:

configuration efficiency	$\eta_{TE\,J} \equiv T_E\, V_H / P_J$
internal efficiency	$\eta_{J\,P} \equiv P_J / P_P$
propulsive efficiency	$\eta_{TE\,P} \equiv \eta_{TE\,J}\, \eta_{J\,P}$

The <u>configuration efficiency</u> tells us how good the hull-propeller or ship design is, while the internal, hydraulic or pump efficiency tells us how good the propulsor design is.

Comparisons

The performance criteria in terms of energy are particularly important in view of comparison of various configurations as discussed in the paper by Karimi.

<u>Often decisions are based on inadequate performance criteria and non-equivalent propulsors</u>. *A historical example is Grim's vane wheel.*

Propulsive performance

The configuration efficiency is

$$\eta_{TE\,J} \equiv T_E\, V_H / P_J = V_H / (V_E + \Delta V/2)\ .$$

Thus the propulsive efficiency

$$\eta_{TE\,P} = \eta_{J\,P} / (1 - w_E + \tau_E/2)$$

depends on three parameters only :

the *internal efficiency*, the *energy wake fraction*

$$w_E \equiv 1 - V_E / V_H$$

and the vorticity parameter

$$\tau_E \equiv \Delta V / V_H = T_E / (\rho\, Q\, V_H)\ .$$

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Vorticity parameter

The vorticity parameter*, another fundamental parameter not 'normally' used by naval architects,* ***clearly shows that only the effective thrust, and thus the effective resistance is energetically relevant.***

In terms of the normalised propulsor 'head'

$$\Delta\varepsilon = \Delta e / (\rho\, V_H^{\,2}/2)$$

the vorticity parameter is

$$\tau = [(1 - w_E)^2 + \Delta\varepsilon)]^{1/2} - (1 - w_E)\ ,$$

and thus in first approximation

$$\tau \approx \Delta\varepsilon / [2\,(1 - w_E)]\ .$$

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Opinion changed

The Committee on Unconventional Propulsors under its chairman Kruppa, TUB Berlin, was fully aware of the advantages of 'talking' in terms of energy flows.

But the following committee went back to the description in terms of momentum flows. As I have pointed out in a contribution to the discussion at the ITTC in Venice 2002 both descriptions have to complement each other if it comes to forces.

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Design procedure

A corresponding method for the design of wake adapted ducted propellers has been proposed and tested. It starts from the condition self-propulsion, of overall zero momentum flow, essentially from the effective resistance and the corresponding net power to be fed into the flow.

It starts from an invariant design goal, including all interactions, not requiring clumsy searches for optima, but concentrating hydrodynamics to the essentials: design, evaluation and testing of the pump proper.

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Nasty by-product

As in pump design everything else is being dealt with in terms of energy flows and the thrust and all interactions are being treated implicitly observing the optimum condition from the beginning!

As in pump design the thrust comes in only at the end, as a nasty by-product. All pumps develop thrust and need thrust bearings. Although pump designers do not want to produce thrust, they cannot avoid it and have to know it in order to design the bearing.

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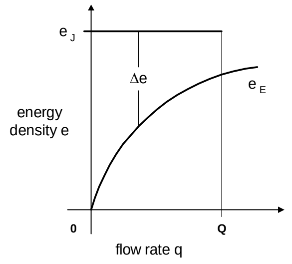
Design goal

‘Invariant’ design goal for all equivalent optimal, wake adapted ducted propellers including all hull-propeller interactions!



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‘Pump’: stator, rotor, duct

‘Pump’: behind *Amtsberg*'s ‘cigar’

Development 'algorithm'

In the paper by Banerjee et al detailed wake measurements have been made in a wind tunnel at NSTL. With the design procedure mentioned the "*Large-scale(?) search for the optimum vehicle-propulsor configuration for fully submerged vehicles" (or its genetic development?)* might have been greatly accelerated, if not unnecessary.

Usually the constraint on the body contour is too narrow, based on the naiv concept of propulsion. In fully integrated designs the hulls do not need to be 'stream-lined', 'tapered'!

Cavitation

The cavitation performance of a similar system has been investigated at NSTL in physical and numerical experiments as decribed in the paper by Kumar et al.

The draft abstract raised questions concerning the the basic hydrodynamical mechanisms, the flow inside the propulsor and the cavitation in a boundary layer.

Cavitation noise

The paper of Chatterjee et al is concerned with the problem of ultra sonic cavitation reduction in combination with decelerating ducts.

The paper by Suryanarayana et al is concerned with differences in cavitation noise of contra-rotating propellers made of different materials. Acoustic experiments in narrow basins suffer from the very narrow useful frequency window.

Pump testing

The pump industry has standards of delivery, so naval architects do not need to re-invent the wheel.

'Integral' testing of complete propulsor systems including the inlet can be performed in by-passes of cavitation tanks as described in the paper of Roussetsky et al. At VWS inlet tests have been done that way in 19xx.

To calibrate flow meters within a confidence interval of 3% is far from trivial for large flow rates; PTB Berlin.

Conclusions

The purpose of this talk was to provide some guide lines and perspectives concerning propulsor hydrodynamics.

As I have demonstrated, in talking about propulsors **hydrodynamic experiments, physical and/or numerical, come in only after simple hydro-dynamic models constituting an adequate normative ship theory have been adopted**.

The examples I have shown do not solve *all* problems, but are paradigmatic in character.

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Anything goes: KISS

Only on this level of abstraction can parameters, performance criteria and development strategies be defined in a professional, efficient fashion.

Paul Feyerabend in his famous treatise 'Against Method' of 1975 stated: 'The only general principle, not impeding progress, is: *anything goes*.' Accordingly I took the freedom to choose the engineering principle

KISS: *Keep it simple, stupid*.

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Power tools …

And I have demonstrated how powerful that is in protecting us from professional superstition and guess work.

The question is *not* to 'disprove' the approach and the conceptual framework developed and applied successfully in various fundamental cases in detail over the past 25 years.

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… of advantage

The 'only' question left is:

If all this could be done, what can be done next?

***Take competitive advantage of the concepts and power tools provided for the solution of other problems at hand*, e. g. the design and evaluation of research strategies and of test techniques, the design of appropriate facilities, the construction of adequate performance criteria etc etc.**

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